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Spatiotemporal variability of fishery-dependent indices for the declining Louisiana Southern Flounder fishery

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Abstract.—In recent years, management agencies across the Gulf of Mexico and southern U.S. Atlantic have recognized Southern Flounder (*Paralichthys lethostigma*) as a declining fish stock. Population declines in coastal Louisiana are exhibited by indices of recruitment and biomass, which have reached levels that present management concerns. To develop a better understanding of this declining fishery we examined fishery-dependent data collected by the Louisiana Department of Wildlife and Fisheries recreational angler harvest survey, referred to as LA Creel. Data were modeled using generalized additive models (GAMs) to estimate temporal components

of recreational Southern Flounder landings in both seasonality and trend. Over the study period (2014–2019), recreational landings exhibited a declining trend statewide. Strong seasonal peaks in the fall were exhibited statewide and regionally among every coastal management zone (i.e., estuary). Understanding the current fishery with the fine-scale resolution provided by the LA Creel survey can be used to help guide future management decisions in the pursuit of a sustainable management strategy inclusive of fishery-dependent information.

Indices of abundance developed from fishery-independent data sources are often preferred over indices developed from fishery-dependent sources in determining the status of fish stocks. Fishery-independent data are collected using systematic and random survey designs that attempt to keep spatial, temporal, and effort elements consistent to gather unbiased abundance data that allow for proportionality between survey catch rates and stock abundance to reasonably be assumed (Hilborn and Walters 1992; Hubert and Fabrizio 2007). The non-random aspects of commercial and recreational fisheries, along with any regulatory changes of the fishery through time, can lead to non-proportionality between fishery catch rates and stock abundance that creates biases when interpreting fishery-dependent data as a measure of stock abundance (Grüss et al. 2019; Tate et al. 2020). Additionally, the non-linear relationship between catchability and stock abundance (Crecco and Overholtz 1990; Wilberg et al. 2009) can potentially lead to hyperstability, where indices of stock abundance ostensibly appear stable while a decline in stock size is occurring (Hilborn and Walters 1992).

Despite the inferential limitations of fishery-dependent data as a measure of stock abundance, broad applications exist for the use of fishery-dependent data in assessing fish populations. A classic example of applying fishery-dependent data as a source of stock size is through the standardization of catch-per-unit-effort (CPUE) to remove the factors not related to changes in abundance and is often used in stock assessments where fishery-independent data is lacking or unavailable (Winker et al. 2013; Okamura et al. 2017; Grüss et al. 2019; Tate et al. 2020). Another popular application of fishery-dependent data includes characterizing the spatial structure of fish distributions and habitats (Pilar-Fonseca et al. 2014; Pennino et al. 2016; Sculley and Brodziak 2020). Fishery-dependent data can also be used to elucidate drivers of fish population fluctuations by evaluating the relationships observed between fishery effort, landings, and stock abundance (Askey and Johnston 2013; van Poorten et al. 2016; Dassow et al. 2020; Feiner et al. 2020). Composition information (e.g., size, age, sex) collected directly from the fishery is also frequently applied to characterize how fish populations and landings within specific regions are structured (Ajemian et al. 2016; Bada-Sánchez et al. 2019; Herdter et al. 2019). Nevertheless, fisheries-dependent data remain underutilized in the management of many fisheries, particularly those for which substantial fisheries-independent data exists.

In recent years, numerous state management agencies have recognized Southern Flounder (*Paralichthys lethostigma*) as a declining fish stock throughout much of the Gulf of Mexico and U.S. southeast Atlantic (Froeschke et al. 2011; Powers et al. 2018; Flowers et al. 2019; West et al. 2020; Erickson et al. 2021). In response to this decline, significant regulatory changes have been implemented in recent years for multiple Southern Flounder fisheries. Although Southern Flounder regulatory changes have not yet been implemented in Louisiana, the most recent stock assessment by the Louisiana Department of Wildlife and Fisheries (LDWF) stated that management actions will be necessary to recover the depleted stock (West et al. 2020). The decline in the Louisiana Southern Flounder population is underscored by the most recent estimates of spawning stock biomass, abundance of age-one recruits, and the total female stock size, all reaching the lowest levels observed in the terminal year of each time-series reported (West et al. 2020; Figure 1).

Fishery-dependent data in Louisiana for marine recreational fisheries is currently collected through the LDWF recreational angler harvest survey (LA Creel), which was developed in 2014 to produce timely recreational landings estimates with a fine temporal resolution (weekly) and a basin-level spatial resolution. Data collected by LA Creel, which utilizes a stratified random survey design, has provided a substantial reference for estimates of recreational fishery harvest in Louisiana. LA Creel became the first Gulf of Mexico recreational state survey to receive full certification from National Oceanic and Atmospheric Administration (NOAA) Fisheries for the estimation of harvest of all recreationally pursued marine fish species (NOAA Fisheries 2018). With fishery-independent abundance indices depicting a declining Southern Flounder stock in Louisiana (West et al. 2020; Erickson et al. 2021), this study evaluated indices developed from LA Creel to better characterize the Louisiana recreational Southern Flounder fishery and determine if the observed decline in fishery-independent indices is reflected within fishery-dependent indices. Due to the biases associated with using fishery-dependent data as an index of stock size without a form of standardization, our evaluation did not seek to provide an additional measure of stock abundance. Rather, our study objectives were confined to evaluating trends within the fishery by answering three primary questions. First, how have fishery-dependent indices fluctuated annually? Second, how does exploitation of the species vary on a seasonal basis? Third, what similarities and differences exist regionally throughout coastal Louisiana when examining the temporal variations in this fishery? Results of this analysis may inform future policy changes based on the angler harvest behaviors elucidated within this fishery and provide a useful approach for assessing spatial and temporal aspects of fishery-dependent data.

[A]Methods

[C]*Data.*–We confined our study to the recreational Southern Flounder fishery in Louisiana, which is the primary source of directed fishery removals statewide (West et al. 2020). Moreover, our study was focused on recreational landings of Southern Flounder within coastal Louisiana as offshore landings account for a negligible proportion of the total recreational landings (LA Creel, unpublished data). For the purposes of this study, LA Creel estimates of *landings* (the number of Southern Flounder estimated to have been harvested each week) and *effort* (the number of angler-trips estimated to occur each week) were evaluated. LA Creel estimates are regionally stratified into five coastal management zones: Calcasieu, Vermilion, Terrebonne, Barataria, and Pontchartrain (Figure 2**)**. The Calcasieu Zone contains the Calcasieu/Sabine and Mermentau River basins; the Vermilion Zone contains the Vermilion/Teche and western Atchafalaya River basins; the Terrebonne zone contains the eastern Atchafalaya River and Terrebonne basins; the Barataria Zone contains the Barataria and western Mississippi River Delta basins; and the Pontchartrain Zone contains the eastern Mississippi River Delta, Breton Sound, and Pontchartrain basins.

The LA Creel survey generates landings estimates of recreationally targeted marine fish species using a complemented survey design, which combines an on-site dockside intercept survey with an off-site effort survey that utilizes both telephone and email contacts. Both the on-site and off-site surveys follow a stratified random sampling structure. Access points utilized within the LA Creel survey include all public sites (e.g., boat ramps, piers, beaches) in coastal Louisiana that are utilized by saltwater anglers. The number of weekly assignments is held constant within each coastal management zone and is based upon the diversity and level of angling activity. As more angling activity occurs during the weekend, assignments fall more frequently during this day-type. During the dockside intercept survey, information on the number of each species harvested is collected from anglers at access points, which are randomly assigned using a probability proportional to size methodology based on the level of angling activity. Angling activity within each site is assessed monthly to optimize site selection. . Species-specific harvest rates are calculated from the information collected in the dockside intercept survey weighted by the day-type (weekend or weekday), site location, and time of each interview (AM or PM). During the off-site effort survey, a random sample of private Louisiana saltwater fishing license holders and Louisiana charter boat license holders are contacted by email or telephone to collect information about the dates and locations of saltwater angling trips. The private angler effort survey sample frame is stratified into five sections based on geographic area, license densities, and license type [north Louisiana, southeast Louisiana, southwest Louisiana, non-resident, and Recreational Offshore Landing Permit (ROLP)]. Sixteen hundred private Louisiana saltwater fishing license holders are randomly selected from the sample frame each week for interviews (400 from the ROLP stratum and 300 from the four remaining strata). The weekly call list from this sample frame is randomized and anglers are contacted until a quota of 800 license holders is reached. For the charter boat survey, 30% of ROLP captains and 10% of non-ROLP captains are randomly selected from the sample frame of Louisiana charter boat license holders and contacted for interviews each week. Angler effort within each coastal zone is estimated by determining the mean effort per angler interviewed and applying this estimate to the total population of licensed anglers with a correction factor for license compliance rates. The harvest rates estimated from the on-site dockside intercept survey and the effort levels estimated from the off-site effort survey are combined to develop a complemented weekly harvest estimate for each coastal zone. In addition to the data provided by the LA Creel Survey (2014–2019), our study also analyzed data collected by the earlier federal recreational marine creel programs (Marine Recreational Information Program and the previous Marine Recreational Fishery Statistics Survey; 2000–2013). Due to the differences between estimation procedures of the LA Creel and federal surveys, LA Creel harvest estimates were calibrated to the historic estimates to develop a continuous time-series of estimates in a common currency (West and Zhang 2018).

[C]*Generalized Additive Model.*–We chose generalized additive models (GAMs) to assess the temporal components within the LA Creel data for a variety of reasons, including: 1) GAMs are capable of exhibiting non-linear and complex relationships between response and predictor variables (Wood 2006), 2) GAMs provide easily interpreted visualizations of these complex relationships, and 3) GAMs offer the flexibility to analyze data within a variety of statistical distributions (Guisan et al. 2002). Weekly landings estimates derived from the LA Creel survey within each coastal management zone were best characterized as count data with overdispersion and frequently contained landings values of zero for each week. Zero-inflated models were explored to evaluate if the frequent zero values in our data were adequately modeled. Results using a zero-inflated negative binomial model were virtually indistinguishable from the results using a negative binomial distribution. Due to the prevalence of the negative binomial distribution in the use of modeling fisheries count data with overdispersion and moderate zero inflation (Barry and Welsh 2002; Drexler and Ainsworth 2013; Dance and Rooker 2019) and the potential overutilization of zero-inflated models (Wood 2020), we opted to model LA Creel estimates using the negative binomial distribution. All statistical analyses were performed using R (R Core Team 2020) and the package *mgcv* (Wood 2006).

GAMs were built under the equation:

$$E[y_{ij}] = g^{-1}\left[\beta_0 + \sum_k S_k(x_k)\right]$$

where $E[y_{ij}]$ is the expected value of the response variable as the number of Southern Flounder landed within each coastal zone, j, during each corresponding weekly period, i. The link function is represented by g, β_0 is the intercept, and S_k is the smoothing function of each predictor variable, x. Temporal components of landings were included as predictor variables within each model in *year* (the corresponding year) and *season* (the corresponding week of the year). Smoothing terms for each predictor variable were represented using thin plate regression splines (*year*) and cyclic cubic regression splines (*season*) penalized from a maximum basis dimension (*k*). The value of *k* was restricted to six (one for each year of data) for *year* and 10 for *season*. Smoothing parameters were selected using maximum likelihood (ML; Wood 2011). The natural logarithm of effort (weekly number of angler-trips within each coastal zone, *j*) was applied as an offset within each model. Models were specified for estimations within two frameworks, one framework for a coastal zone-specific model and one framework for a statewide model. Within the coastal zone-specific model, weekly recreational landings from all coastal zones were pooled as the dependent variable and five smoothing terms were produced for each coastal zone for *year* and *season*. A random effect for each coastal zone, *j*, was applied within the coastal zone-specific model allowing variation to occur within each smooth in shape. Within the statewide model, weekly recreational landings from all coastal zones were pooled as the dependent variable and a smoothing term was produced for *year* and *season*. A random effect for each coastal zone, *j*, was applied within the statewide model to account for the variability within each coastal zone. Significance of each smoothing term was evaluated at $\alpha = 0.05$. Within both statewide and coastal-specific models, substantial positive residual autocorrelation provided evidence of serial correlation, a common issue confounding time-series analysis (Hamilton 1994). To account for serial correlation within LA Creel landings estimates, a first-order autoregressive term (Wood 2006) was nested within each coastal zone time-series for both the statewide and coastal zone-specific model frameworks.

[C]*Synchrony*.–To quantify the similarity of temporal patterns in Southern Flounder landings throughout Louisiana, synchrony of coastal zone-specific model predictions were quantified through the calculation of Spearman correlation coefficients with corresponding asymptotic *p*-values approximated using the *t*-value distribution (Harrell 2020). Significant relationships were evaluated at $\alpha = 0.05$. Weekly predictions from 2014–2019 were used in this analysis, making each weekly time-series 313 periods long. With five total time-series (Pontchartrain, Barataria, Terrebonne, Vermilion, Calcasieu), 10 unique correlation coefficients were calculated.

[A]Results

From 2000–2016, annual landings estimates of Southern Flounder in Louisiana remained relatively close to the 20-year average (2000–2020) of 200,000 fish per year. During the years 2017–2019, annual landings estimates substantially declined to levels approaching or below 50% of the 20-year average (Figure 3). Louisiana Southern Flounder landings estimates were driven by harvest within the Calcasieu Zone where at least 55% of the annual Southern Flounder landings in Louisiana have been estimated to occur over the LA Creel period (Figure 4).

For the GAM applied to statewide data, the smoothing term for *year* was significant ($p < 0.001$; Table 1) indicating variability in landings over the time-series examined. The statewide time-series displayed a sharp decline in 2017 with a modest increase in 2019 (Figure 5). Over the entire time-series, Southern Flounder landings have declined statewide during the LA Creel period. A significant smoothing term ($p < 0.05$; Table 1) for *year* indicated variability in landings over the time-series in the Calcasieu, Pontchartrain, Barataria, and Terrebonne Zones (Figure 5). Landings in the Barataria and Terrebonne Zones exhibited declines beginning approximately in 2017 with subsequent increases in 2019. The Calcasieu and Pontchartrain Zones exhibited a moderate decline over the entire time-series. Within the Vermilion Zone, landings did not display significant variability over the time-series.

The smoothing term for *season* was significant ($p < 0.001$; Table 1) in the statewide model and displayed a strong peak in fall landings (Figure 6). In the coastal zone-specific model smoothing terms for *season* were significant ($p < 0.05$; Table 1) within every coastal zone, with strong landings peaks in the fall, specifically during the month of November (Figure 6).

The relationships between each coastal zone-specific prediction time-series were all significant ($p < 0.001$) and positively correlated. Each correlation coefficient indicated relationships ranging from 0.22–0.67 (Figure 7).

[A]Discussion

This study examined recreational landings in the Louisiana Southern Flounder fishery, indicating that landings have declined statewide in recent years, but more importantly provided a fine-scale spatial and temporal understanding of this decline. While only using data from the six-year LA Creel time-series, the observed decline in landings is significant statewide and consistent with the range-wide declines reported by numerous state agencies (Erickson et al. 2021). Extending the LA Creel time-period to the time-series of hindcast landings estimates places the context of the decline over a 20-year period.

Our analysis quantified and confirmed the impact of the fall harvest within the recreational Southern Flounder fishery in coastal Louisiana. Although the fall harvest is well defined by those familiar with the resource (Gulf States Marine Fishery Commission 2015), the seasonality of recreationally harvested Southern Flounder in coastal Louisiana has not been documented in the published literature and our study provides a baseline to understanding future seasonal shifts within this fishery. The peak in fall harvest coincides with the large-scale seasonal migrations that Southern Flounder make to offshore waters from the estuarine environment as water temperatures cool (Craig et al. 2015). As Southern Flounder move through restricted passes to reach offshore spawning grounds, concentrations of fish become increasingly vulnerable to recreational harvest as indicated by the peaks observed in the fall landings.

The resolution of data characterizing specific coastal zones within Louisiana provided the opportunity to evaluate the unique spatial variability that exists in the Louisiana Southern Flounder fishery. Our analysis provided evidence of the substantial influence that the Calcasieu Zone holds on coastal Louisiana recreational Southern Flounder landings. Additionally, the Vermilion Zone did not display significant variability over the LA Creel period in our analysis of annual trend, in contrast with the variability observed within all other coastal zones and statewide. The Vermilion Zone also provided the smallest magnitude of landings within any coastal zone with total landings accounting for less than three percent of statewide landings over the entire LA Creel period. The inferior scale of landings in the Vermilion Zone may be a driving force behind the diverging variability in annual trend. Moreover, our analysis of synchrony displayed significant positive correlations between the Vermilion Zone and all other coastal zones, providing some additional evidence of variability within this zone. A further evaluation of estuary-specific habitat and bay morphology may provide evidence to why differential exploitation in magnitude and annual trend occurs within the Calcasieu and Vermilion Zones. To further evaluate the potential for coastal zone-specific stock structure, age and size composition data could be evaluated within each coastal zone to determine if sub-populations exist within the statewide stock.

[B]Study Limitations and Strengths

This study was reliant upon probabilistic sampling methods that are commonplace in the estimation of recreational effort and landings. While there are limitations to this type of data collection, namely in the inferences that must be made from a fixed amount of interviews over a sampling period (Midway et al. 2020), no substitutable alternatives (e.g., electronic self-reporting) currently exist in the collection of recreational fishery-dependent data, specifically within coastal Louisiana. Absent significant advances in non-probabilistic sampling designs and the willingness of users to adopt new technologies (Midway et al. 2020), robust probabilistic sampling methods for fishery-dependent data must continue in order to characterize and understand changes in harvest though time and space.

With the availability of only six years of data at the spatial and temporal resolutions of the LA Creel survey, the trends displayed by our models can only be placed in this limited context. However, the fine temporal resolution of the LA Creel survey data allows for inferences to be made over the six-year window. The decline displayed statewide over this period highlights the magnitude of the reduction that is occurring in the Louisiana Southern Flounder fishery. Additionally, the spatial resolution of the LA Creel survey allows coastal zone-specific inferences to be made throughout coastal Louisiana, a spatial distinction that was not previously available with Louisiana recreational fishery estimates prior to the implementation of LA Creel. The LA Creel survey characterizes recreational fisheries with greater resolution, greatly improves the monitoring capabilities within coastal Louisiana fisheries, and allows for real-time and impactful management decisions to be made in preserving the future of significant recreational fisheries.

The framework offered by a GAM statistical approach provided a significant strength in our evaluation. While other approaches were evaluated, particularly in tree-based machine learning approaches and generalized linear models (GLMs), the GAM approach was recognized as the strongest statistical fit for our evaluation. The flexibility offered by a semi-parametric approach with the ability to provide data-driven response curves (Yee and Mitchell 1991) led to our decision to use a GAM over a GLM. The simplicity offered by fitting the most parsimonious model (rather than risking overfitting with several models; Carvalho et al. 2018) and the improved accuracy in modeling smooth functions (Elith et al. 2008) led to our decision to use a GAM over a tree-based machine learning approach. GAMs were identified as the best statistical tool for this investigation with the ability to provide data-driven response curves of highly non-linear and non-monotonic relationships (Yee and Mitchell 1991; Wood 2006), the capacity to account for serial correlation (Wood 2006), and the flexibility to model data in a variety of statistical distributions (Guisan et al. 2002).

[B]Future of the Fishery

The decline in landings of Southern Flounder in Louisiana may be the result of various drivers or the interactions among multiple drivers, including changing angler behavior or a decline in stock size, among other possibilities. Angler behavior, in the number of angling trips, has not significantly changed during the LA Creel period within the Pontchartrain or Terrebonne Zones;

however, the Barataria, Vermilion, and Calcasieu Zones all displayed significant changes in effort over this period. Effort within the Barataria Zone has increased while effort in the Vermilion and Calcasieu Zones has declined. These outcomes may have a significant effect on Southern Flounder landings, specifically within the Calcasieu Zone as this coastal zone has the strongest influence on statewide landings. The Calcasieu Zone effort declined in mean weekly trip estimates from 7,104 trips in 2014 to 5,753 trips in 2019. Since 2017, the target species from each dockside intercept interview has been recorded by the LA Creel survey. The annual percentage of anglers targeting Southern Flounder in coastal Louisiana has remained relatively low from 2017–2020, annually ranging between 1.4%–1.6% statewide. However, these percentages varied seasonally and spatially, particularly within the Calcasieu Zone and during the month of November. During November within the Calcasieu Zone, the percent of anglers targeting Southern Flounder was 21.9% from 2017–2020. This percentage is a substantial increase from all other months during that period, which averaged 4.0%. Moderate increases in the percentage of anglers targeting of Southern Flounder were exhibited in other coastal zones during the month of November; however, these increases were negligible in comparison to the increases in the Calcasieu Zone. The substantial increase in targeting behavior during the month of November is likely a significant factor in the Calcasieu Zone's influence on statewide landings. Continued monitoring of Louisiana angling behaviors are necessary to precisely determine if changing behaviors of anglers are driving fluctuations in Southern Flounder landings.

With estimates of recruitment and stock size for Louisiana Southern Flounder reaching the lowest levels recorded (West et al. 2020), it appears that the reduction in landings of Southern Flounder in Louisiana is related to a corresponding decline in stock size. Moreover, an important factor to consider when evaluating trends in fishery-dependent data is that declines in stock size may be masked by hyperstability. There are numerous examples of fisheries where hyperstability has concealed declines among fish stocks that exhibit aggregating behaviors (Erisman et al. 2011; Sadovy de Mitcheson and Erisman 2012; Dassow et al. 2020). The aggregating behavior of Southern Flounder during the fall migration (Gulf States Marine Fisheries Commission 2015) leads to increased vulnerability of the stock as Southern Flounder move through coastal bottlenecks to reach spawning grounds. The fact that statewide recreational estimates of the Louisiana Southern Flounder fishery currently depict a decline in landings is a meaningful indicator of potential overfishing and a depleted stock that warrants management attention.

Considering this species marked decline, attributes of the recreational Louisiana Southern Flounder fishery demonstrated by the findings of this study can provide insight into future management strategies. The reduction of spawning stock size can significantly impact Southern Flounder populations during the fall migration and has resulted in seasonal restrictions applied to recreational Southern Flounder fisheries throughout much of their range. Our findings indicate that a seasonal restriction during the fall migration would likely produce a reduction in Southern Flounder harvest, an action that may be necessary for the recovery of this declining stock. All coastal zones indicated positively correlated time-series and strong similarities existed within the seasonal trends produced in each coastal zone displaying the converging attributes of each coastal zone. Moreover, the estuarine fidelity that Southern Flounder exhibit as they return to coastal Louisiana is unknown and future research is necessary to examine the level of connectivity among Louisiana coastal zones, as well as the connectivity across state boundaries. For these reasons, the management of Southern Flounder in Louisiana would likely benefit from a statewide strategy rather than a region-specific approach.

With Southern Flounder declines occurring throughout their range, extending across multiple jurisdictional boundaries in which various regulatory strategies exist, there is a high capacity for a universal driver in the decline of Southern Flounder. Southern Flounder are susceptible to the effects of a changing climate as this species exhibits environmental sex determination in which during larval development suboptimal water temperatures can lead to increased ratios of phenotypic males (Luckenbach et al. 2009; Honeycutt et al. 2019). Additionally, laboratory studies have also shown that warming water temperatures significantly affect the success of hatching and larval development of Southern Flounder (van Maaren and Daniels 2001). As documented water temperatures have risen over the past few decades within the same locations and times that Southern Flounder develop after hatching (Erickson et al. 2021), the role that climate has played as a driver of stock size in Louisiana is likely to be significant. While future management strategies have the potential to help mitigate further declines in Louisiana Southern Flounder stock size, it is important to note that reduced exploitation may not have the potential to fully recover the stock considering the role that climate will continue to play in this species' decline.

Recreational fisheries are dynamic systems that provide numerous management challenges as changes occur in climate, environment, and culture (Elmer et al. 2017; Brownscombe et al. 2019; Holder et al. 2020). The approaching difficulties of managing recreational fisheries that will be heavily influenced by these changes underscores the importance in filling the information gap that exists between human dimensions studies and recreational fisheries (Hunt et al. 2013). One way that managers can more closely understand the behaviors of anglers is through an evaluation of fishery-dependent data. Fishery-dependent data provides insights into fisheries that are often underutilized yet commonly collected by management agencies. When management action is required, understanding the various components of recreational fishery harvest can aid in making a management decision that is not only biologically sound but also makes a meaningful impact in preserving the benefits that fisheries provide to anglers.

[A]Acknowledgments

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Tables

Table 1. GAM smoothing term significance within the statewide model and coastal zone-specific model. Significant terms ($p < 0.05$) are in boldface.

Region	**Smoothing Term**	***p*-value**
Statewide	*time*	**< 0.001**
	season	**< 0.001**
Calcasieu	*time*	**0.028**
	season	**< 0.001**
Vermilion	*time*	0.269
	season	**< 0.001**
Terrebonne	*time*	**< 0.001**
	season	**0.008**
Barataria	*time*	**< 0.001**
	season	**< 0.001**
Pontchartrain	*time*	**0.008**
	season	**< 0.001**

Figure Captions

Figure 1. Estimates of abundance for Louisiana Southern Flounder (1982–2018). Shaded areas represent two asymptotic standard errors above and below the estimate. a) Spawning Stock Biomass. b) Abundance of Age-One Recruits. c) Total Female Stock Size (asymptotic standard errors were not calculated for this estimate).

Figure 2. Louisiana coast regionally segmented by the LDWF coastal management zones.

Figure 3. Annual Southern Flounder landing estimates from the LA Creel survey (2014–2019) and estimates hindcast to the historic Marine Recreational Information Program time-series (2000–2013).

Figure 4. Annual Louisiana Southern Flounder landings within each coastal management zone.

Figure 5. Partial effect plots for the smoothing term *year* in the statewide model and in the coastal zone-specific model. Shaded areas represent two standard errors above and below the smooth curve estimate. Dashed lines mark zero-effect.

Figure 6. Partial effect plots for the smoothing term *season* in the statewide model and in the coastal zone-specific model. Shaded areas represent two standard errors above and below the smooth curve estimate. Dashed lines mark zero-effect.

Figure 7. Correlation matrix of weekly recreational LPUE for Southern Flounder within each coastal management zone. Significant relationships ($p < 0.05$) are indicated by an asterisk.

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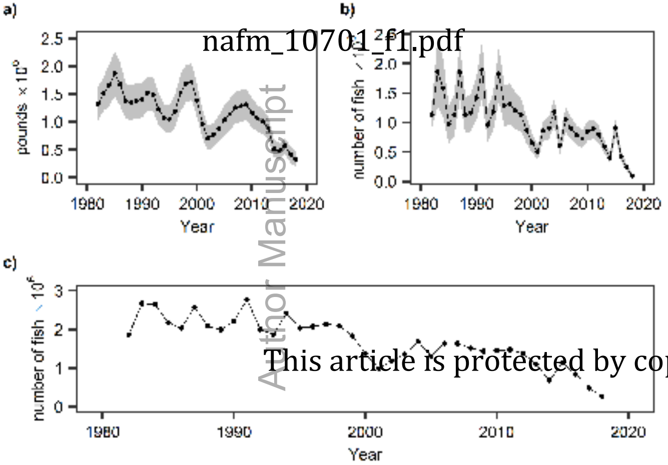

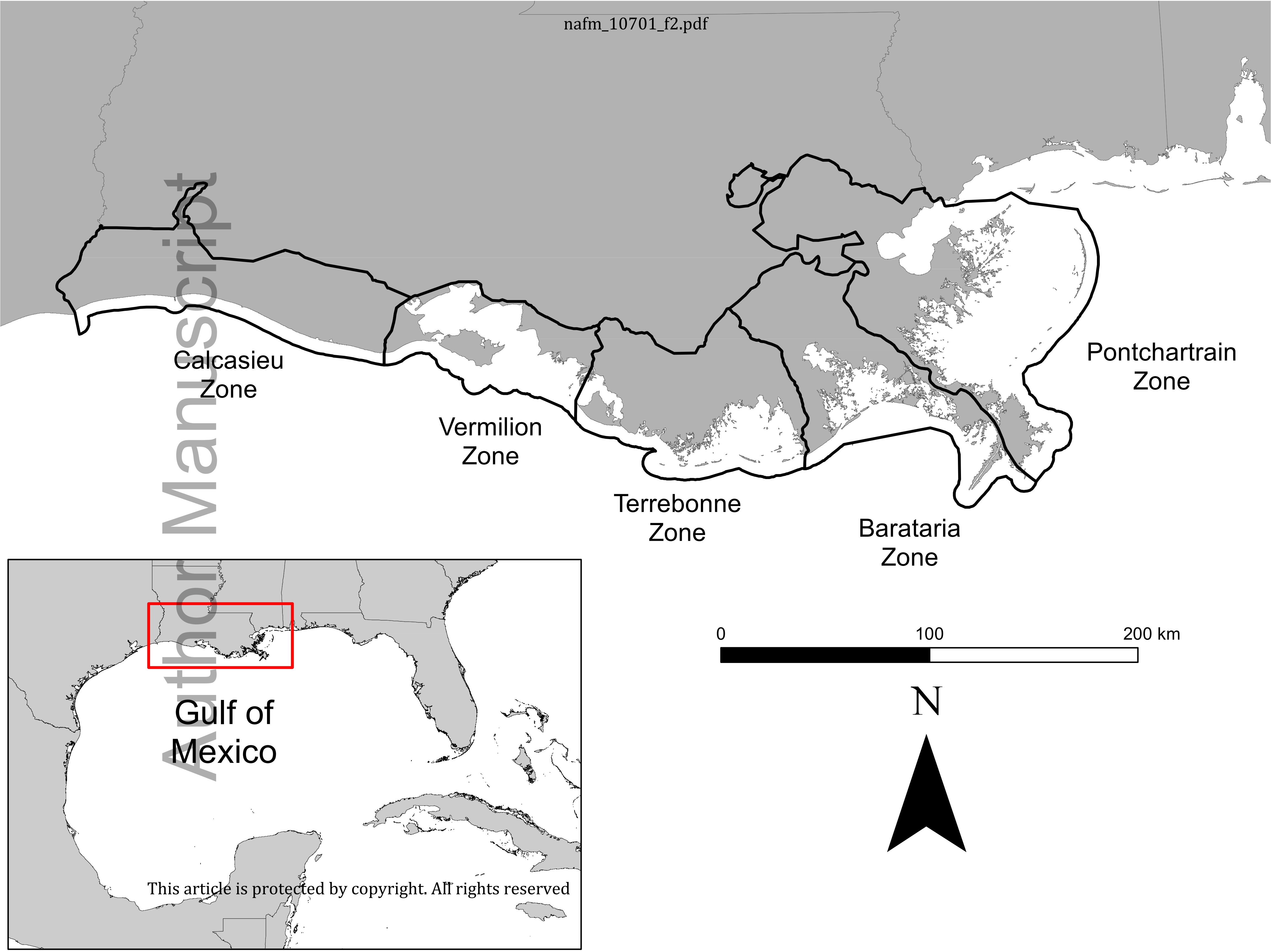
Calcasieu
Zone
Vermilion
Zone
Terrebonne
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Barataria
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Pontchartrain
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Mexico
0
100
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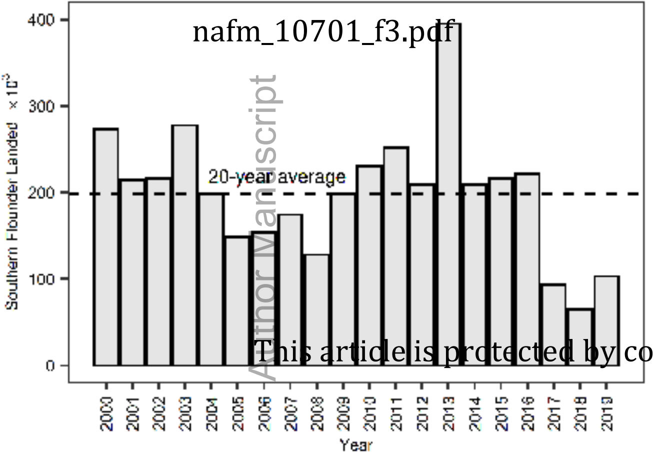
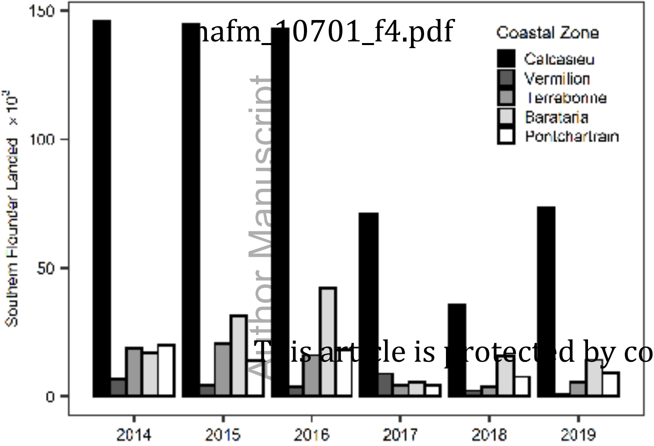
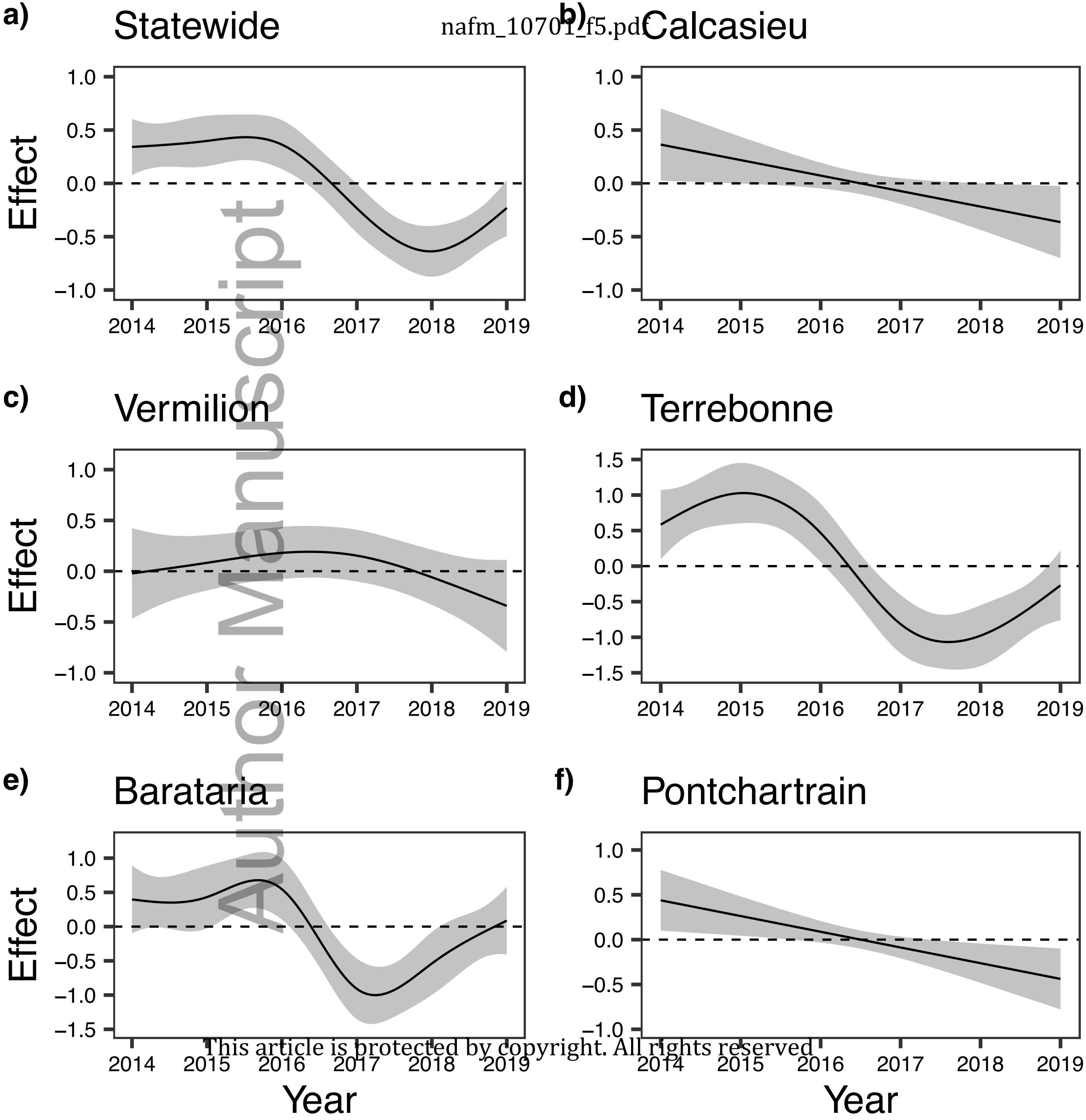
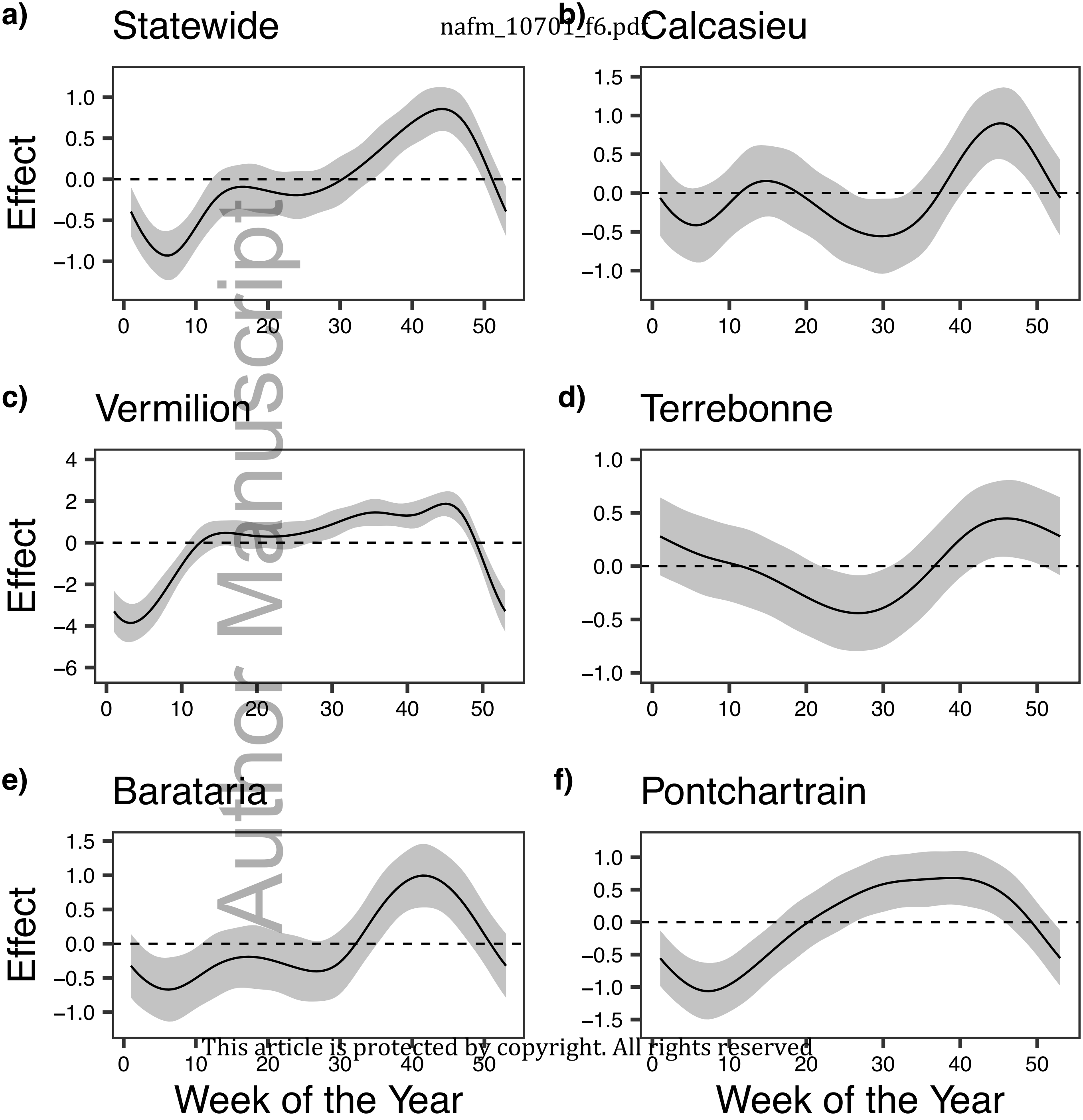



150
100
50
0
Southern Flounder Landed × 10³
2014
2015
2016
2017
2018
2019
Coastal Zone
Calcasieu
Vermilion
Terrabonne
Barataria
Pontchartrain


a)
Statewide
b)
Calcasieu
c)
Vermilion
d)
Terrebonne
e)
Barataria
f)
Pontchartrain
Effect
Effect
Effect
Year
Year
1.0
0.5
0.0
−0.5
−1.0
1.5
−1.5
2014
2015
2016
2017
2018
2019


a)
Statewide
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Pontchartrain
Effect
Effect
Effect
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
4
2
0
−2
−4
−6
0
10
20
30
40
50
Week of the Year
Week of the Year

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